Defense Technical Information Center
Compilation Part Notice

ADP014128

TITLE: Advanced Engine Monitoring and Diagnosis Systems: Actual System for the EJ2OO Engine of the EuroFighter 2000 Aircraft and Future Trends

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Aging Mechanisms and Control. Symposium Part A - Developments in Computational Aero- and Hydro-Acoustics. Symposium Part B - Monitoring and Management of Gas Turbine Fleets for Extended Life and Reduced Costs [Les mecanismes vieillissants et le controle] [Symposium Partie A - Developpements dans le domaine de l'aeroacoustique et l'hydroacoustique numeriques] [Symposium Partie B ...

To order the complete compilation report, use: ADA415749

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP014092 thru ADP014141

Advanced Engine Monitoring and Diagnosis Systems:
Actual System for the EJ200 Engine of the EuroFighter 2000 Aircraft and Future Trends

Thomas Zoller
MTU Aero Engines GmbH
Dept.: TKRS
Dachauer Straße 665
80976 Munich, Germany
Thomas.Zoller@muc.mtu.de

Table of Contents

1   Introduction

The EJ200 engine for the EuroFighter 2000 military aircraft will, like other modern military jet engines, operate in usage scenarios characterised by increased complexity and reduced turn-around times. Additionally, the limited defense budgets force the need for a continuous reduction of maintenance effort and cost and for methods for reducing the engine life cycle costs.
These requirements and the increased complexity of the engine system stimulate the continuous improvement of the associated control and monitoring systems.

Ground based Engine Health Monitoring (EHM) Systems in conjunction with on-board monitoring systems form an essential part of the whole system to aid the fulfilment of the above requirements.
Key areas for the ground-based systems to better contribute to the fulfilment of these requirements are a better automation of the monitoring tasks, improved fault diagnosis and localisation and a better guidance of maintenance personnel.

The new and comprehensive Engine Health Monitoring System, which is planned to be used for the EJ200 engine of the EuroFighter 2000 aircraft, is described. This system will provide engine health monitoring and diagnosis for areas like life usage monitoring, engine performance monitoring, supervisory and diagnosis of engine vibration and an advanced fault detection and location system. Engine related logistics and maintenance tasks will also be supported. The EHM will be part of the EuroFighter Ground Support System (GSS), which will be shortly described.

Critical areas and possible improvements of actual engine monitoring systems are described and their potentials to better fulfil the requirements are discussed. This includes the extension of the monitoring functionality as well as improvements of the EHM architecture related to the inclusion of the EHM into the overall Ground Support System of the aircraft and the development process for future engine monitoring, diagnosis and logistic support systems.

2   The EuroFighter Ground Support System

The Ground Support System for the EuroFighter is currently developed by Partner Companies of the four EuroFighter partner nations United Kingdom, Italy, Spain and Germany.

The system will cover all logistic support tasks at the flight-line of the EF2000 on main operating bases as well as on forward operating bases and during deployment.

In accordance with the major support tasks at the flight-line, the GSS is structured into the following main components:

- Mission Support System
- Engineering Support System
- Ground Loading and Data Transfer Unit

The mission support system is the part of the GSS that is mainly responsible for the operational support of the aircraft weapon system. It will cover all tasks related to mission planning and preparation, briefing, debriefing, mission analysis, reporting and statistics.

All engineering and logistics support for the EF2000 is performed via the Engineering Support System (ESS). The ESS comprises of a number of sub-systems:

- EuroFighter Logistics Software (Asset Management, Forms and Records, Maintenance Management Status Monitoring, Reports/Statistics/Analysis)
- Engine Health Monitoring (EHM; engine monitoring and diagnosis, configuration of the on-board engine monitoring system)
- Structural Health Monitoring (SHM; airframe monitoring and diagnosis)
- Secondary Power System Monitoring (SPS; monitoring of the secondary power system)
- Aircraft System Health Software (ASH; initial processing of downloaded data)
- IETP-Browser (Display of technical documentation)
- Experience Capturing System (ExCS; build-up of an experience database from maintenance information)
- System Services Software (basic functions such as interfaces to the operating system, database management, external interfaces, user management, audit logging for all sub-systems)

The ground loading and data transfer unit is responsible for all tasks related to the upload of aircraft application software and of multi-mission data and for the download of aircraft configuration data and of the data from the Crash Survivable Memory Unit (CSMU) in the case of an aircraft incident.

The GSS will be fully integrated into the National logistic support infrastructure of the different EuroFighter nations.

This paper will concentrate on the Engine Health Monitoring System, this being part of the Engineering Support System.

Engine Health Monitoring System of the EJ200 Engine

The Engine Health Monitoring System (EHM) as an essential part of the Engineering Support System is responsible for all ground based engine condition monitoring and failure diagnosis tasks for the EJ200 engine at the flight line. Maintenance management and the support of the maintenance personnel via technical publications and repair instructions are not in the responsibility of the EHM. These facilities are covered by other sub-systems of the ESS

The EHM is seamlessly integrated into the ESS. It is no separate software application. Instead of this it is realised as a number of software components which are included into the ESS application. There are no direct interfaces between the EHM and systems outside the ESS. All interfaces to the outside world, e.g. for the data transfer to and from the aircraft, with other logistic support systems or with the national IT systems of the airforces are implemented using common facilities of the ESS. All basic services such as database access, user authorisation, security features, audit logging, file access or printing are also provided by the system services part of the ESS.

3   The Engine Monitoring, Diagnosis and Logistic Support System for the EJ200 Engine

The following figure gives an overview about the architecture of the monitoring and ground support system for theEJ200 engine. The system comprises of

- an on-board system for engine control, monitoring and diagnosis,
- the data transfer devices that are used to transfer engine related data
- the Engine Health Monitoring System as part of the Engineering Support System of the GSS.

The figure also shows the data paths for engine data transfer.
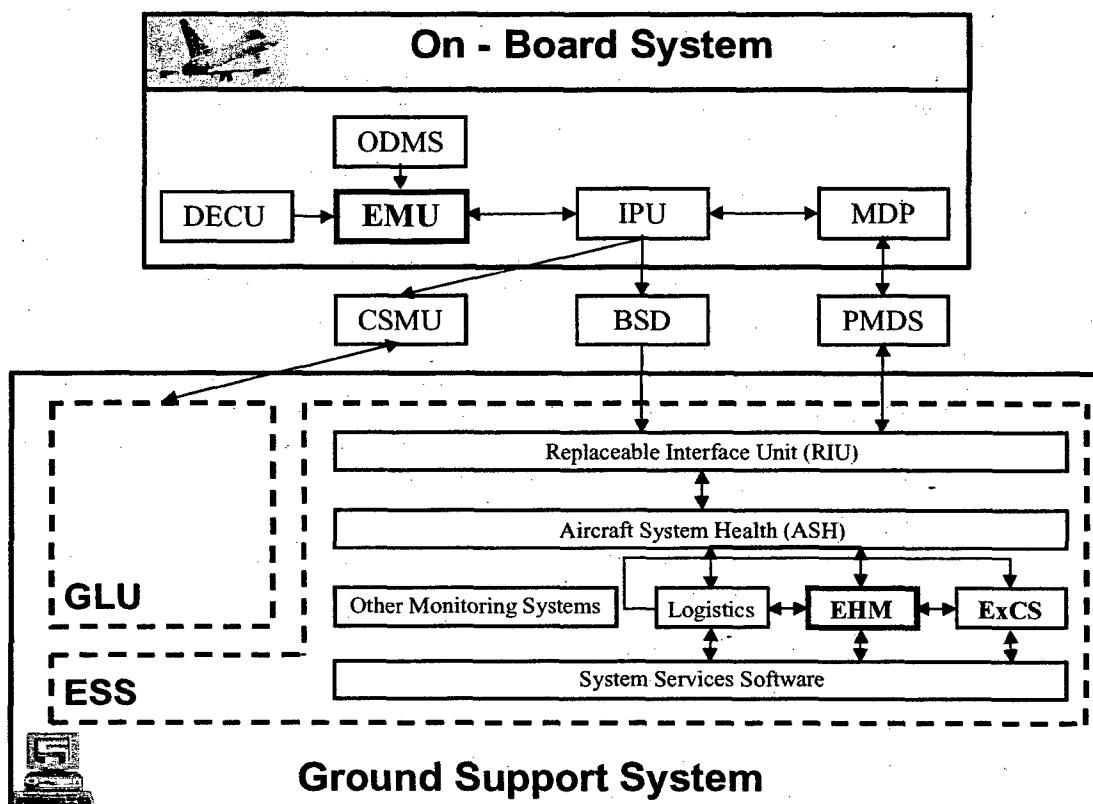
Figure 1: Architecture of the Engine Monitoring and Ground Support Systems of the EuroFighter

Abbreviations used on the figure:

DECU:	Digital Electronic Control Unit	EMU:	Engine Monitoring Unit
ODMS:	Oil Debris Monitoring System	IPU:	Interface Processing Unit
MDP:	Maintenance Data Panel	PMDS:	Portable Maintenance Data Store
BSD:	Bulk Storage Device	CSMU:	Crash Survivable Memory Unit
EHM:	Engine Health Monitoring	ExCS:	Experience Capturing System
ESS:	Engineering Support System	GLU:	Ground Loading (and Data Transfer) Unit

For a description of the system parts refer to sections 2, 3.1, 3.2 and 3.3 of this paper.

3.1 On-board System

The data used for monitoring and diagnosis of the engine are recorded and initially analysed by the on-board systems during flight and immediately after engine shutdown. On-board analysis covers the detection of all engine system failures, which prevent or significantly decrease the operational capabilities of the engine.

The on-board system comprises of the following control and monitoring devices, that are involved in engine related data collection and transfer:

- The Engine Monitoring Unit (EMU)
  The EMU is the key system for the on-board monitoring of the whole engine system including the engine accessories.
  The EMU directly supervises the engine configuration, the life usage of critical engine parts and the actual level of engine vibrations.
  The results of these supervisory tasks and the supervisory results delivered from other engine accessories (DECU, ODMS) are stored and analysed to allow a continuous real-time classification of the condition of the engine system and immediate detection of engine defects during operation.
  The supervisory and analysis functions of the EMU can be widely adapted to the configuration of the engine and to changed monitoring and diagnosis requirements. For this purpose configuration data sets can be transferred from the Ground Support System to the EMU.
  The analysis results, including information about detected engine errors and parameters describing the actual condition of the engine are transferred to the Interface Processing Unit (IPU) for distribution to the data transfer devices and to the Maintenance Data Panel (MDP).

- The Digital Electronic Control Unit (DECU)
  The DECU is the engine control device of the EJ200 engine system. As part of this task, all sensors and actuators of the engine are continuously supervised. The results of this supervisory logic and information about the actual status and condition of the engine such as engine parameters and information about critical events (engine surge, flame out etc.) are continuously transferred to the EMU for storage and inclusion into engine condition monitoring and failure diagnosis. Additionally, in the case of detected failures of the engine or its accessories, detailed information about the failure found and actual engine parameters are stored by the DECU for detailed analysis in non-volatile memory.

- The Oil Debris Monitoring System (ODMS).
  This device is responsible the supervisory of oil debris. Information about actual oil debris and the exceedance of debris limits are reported to the EMU.

- The Interface Processing Unit (IPU)
  With respect to engine related data the IPU acts as a data transmission and distribution system.

- The Maintenance Data Panel (MDP)   –
  The MDP is a display device that is directly attached to the aircraft. Information about failures and special events that have been detected by the different on-board systems are displayed on the MDP after flight. So the MDP is an initial point for aircraft and engine maintenance by providing a first overview about the aircraft and engine condition to the maintenance personnel.

3.2 Data Transfer Devices

The engine related data that have been collected by the on-board systems are transferred after flight to the Ground Support System via the following data transfer devices:

- The Portable Maintenance Data Store (PMDS).
  All regular maintenance data for all sub-systems of the aircraft, including the engine related data, are transferred between the on-board systems and the Ground Support System via this device.

Due to the limited capacity of the PMDS, the continuous storage of engine parameters or other aircraft data for a whole flight is not possible. Instead of this only information about detected failures/events, small snapshots of characteristic engine parameters at the time when the failures/events have been detected and limited information about the actual condition of the engine (e.g. life accounts, vibration signature) can be recorded on this device.

In addition to the downloaded flight data, the data-sets to configure the monitoring and diagnosis functions of the on-board system are uploaded from the GSS to the EMU via the PMDS.

The PMDS is installed during each flight or ground run. The capacity of this device allows the storage of maintenance data from up to 5 aircraft cycles (flights or ground test runs).

- The Bulk Storage Device (BSD)
  The purpose of this mass storage device is to allow the continuous recording of characteristic engine or aircraft parameters during a whole flight to support special investigations on ground. The BSD is attached to the aircraft only in the case of such investigations. Predefined data-sets can be recorded for one flight to support different types of investigations about engine or aircraft aspects. Examples are the engine performance, vibration or the stress to the aircraft structure.
  The BSD data are downloaded to the GSS for display and for transfer to other systems (e.g. analysis systems in the National Support Centre or at Industry). An automated analysis of these data by the GSS or the EHM is currently not foreseen.

- The Crash Survivable Memory Unit (CSMU)
  This device stores aircraft and engine data to support investigations after serious incidents or accidents. The CSMU is always attached to the aircraft. The data stored by this device are not read on a regular basis.
  In the case of events the CSMU data can be read and displayed by the Ground Support System. The data are then transferred to the authorities performing the investigations of these data. An automated analysis of these data by the Ground Support System is currently not planned.

3.3 Engine Health Monitoring System as Part of the EuroFighter ESS

The following figure gives an overview about the fundamental architecture of the Engine Health Monitoring System:
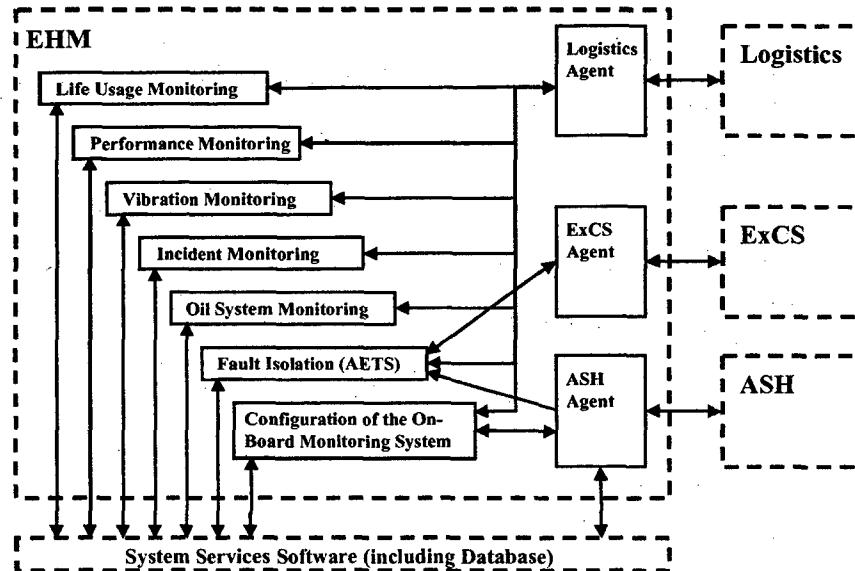

Figure 2: Structure of the EHM System

The different monitoring functions of the EHM system are described in the next section.

As previously shown, the monitoring and diagnosis functions of the Engine Health Monitoring system are mainly built on data that have been recorded by the EMU, DECU and ODMS during flight and transferred to the GSS via the PMDS. In the GSS these data are read by an interface unit and transferred to the EHM.

After reception by the EHM, the data are checked for completeness, consistence and plausibility and stored to the EHM partition of the ESS database. Engine defects that have been detected by the on-board systems are reported to the Logistics sub-system of the ESS to initiate the necessary maintenance actions.

The downloaded data are displayed on user request to allow their manual analysis.

The EHM will implement a number of automated analyses of the downloaded data, such as long term trend analyses or pattern recognition that extend the limited analyses of the on-board systems. These sophisticated analyses cannot be performed by the on-board systems due to the limited computational capacity of the these systems and due to the non-availability of data from more than one engine run.

Engine defects or changes in trends that are manually or automatically detected within the EHM are also reported to the Logistics sub-system of the ESS to initiate the necessary maintenance activities.

The EHM is also responsible for the handling of the configuration data sets that are needed to adapt the monitoring functions of the on-board system to the engine configuration and to the actual monitoring requirements. For this purpose preconfigured, authorised data sets delivered from Industry or national authorities are imported into the EHM and prepared for upload to the EMU.
Only a limited number of parameters in the configuration data sets such as information about the configuration of the engine or the (de)activation of certain monitoring functions can be manipulated within the EHM.

3.4　Functionality of the Engine Monitoring and Diagnosis

The monitoring and diagnosis functions for the EJ200 engine are split into a number of functional areas that are presented in the following sub-sections.

Life Usage Monitoring

It is a common requirement to todays engine systems to optimise the usage time of all parts of the system to extend the life of those parts and the maintenance-free periods to reduce the system and maintenance costs. The Life Usage Monitoring function for the EJ200 engine is responsible for the supervisory of the life span of a number of critical parts. The length of life of these parts strongly depends on their usage profile (strain).
The actual life accounts of these parts are updated by the on-board system depending from the usage profile.
The EHM retrieves the actual life accounts after each flight and supervises the update of these accounts by performing plausibility checks. Fill-in factors are used within the EHM to correct the life accounts in the case of errors due to defects of the on-board system (e.g. sensor defects or defects of the memory storing the accounts). It is planned to automatically adapt these fill-in factors to the real usage profile. The corrected life accounts are uploaded to the EMU before next engine run.
Additionally, the EHM will provide trend analyses of the life accounts to predict the expected remaining life of the supervised parts. This improves predictability and planning of maintenance actions due to life limit exceedance.

Performance Monitoring

The task of the Performance Monitoring function is to provide a constant thrust level over the life of the engine.

For this purpose characteristic engine parameters are recorded at "stabilised" engine conditions. These recorded parameters are used within the EMU to supervise the actual thrust level and to calculate correction factors that are used by the engine control system to adapt engine control to guarantee the required thrust level.

The EHM supervises this functionality of the on-board system and performs a thrust level trend analysis in order to detect engine problems that result in a rapid deterioration of the engine and to forecast the exceedance of thrust correction limits requiring maintenance activities or the replacement of an engine.

Vibration Monitoring

The Vibration Monitoring function continuously supervises the vibration level of the engine. Two sensors are attached to the engine for this purpose. The measured sensor signals are continuously supervised for limit exceedance or sudden changes of the vibration level that could be caused by impending engine defects. Additionally, characteristical parameters and vibration signatures are recorded during flight for transfer to the EHM.

Within the EHM these data will be used to perform engine vibration trend analyses in order to allow the early detection of impending defects. Information about the vibrational characteristics of an engine will be used by pattern comparison algorithms in order to detect engine defects before the vibration levels are exceeded and to support the localisation of defects.

Fault Isolation (AETS)

The whole engine system including sensors, actuators, engine accessories and the behaviour of the engine are continuously supervised by the on-board devices. The defect information delivered from the different supervisory functions is combined by the on-board Advanced Engine Testability System (AETS). Failures are localised at the level of (Flight)Line-Replaceable-Items (LRIs) to give an indication to the maintenance personnel about the source of a defect and the necessary maintenance activities to fix it.

This information is displayed on the MDP after the flight in the form of 'Maintenance Messages'.

Not all defects can be localised completely and reliably by automated analyses. In these cases the EHM will support the isolation of a failure by guiding the maintenance personnel through a manual fault isolation process. The system will propose manual inspections. The results of these inspections will be recorded and used by the EHM to further isolate the failure.

Oil System Monitoring

The task of the Oil System Monitoring function is to supervise the oil consumption of the engine and the oil debris level. A limit exceedance will be reported in both cases. Additionally long term trend analyses will be performed to detect impending engine defects.

Incident Monitoring

In the engine monitoring and diagnosis system, an Incident means each event or occurrence of a failure, that affects the usability or safety of the engine. Single defects of redundant systems are not considered as Incidents.

The Incident Monitoring function collects and records information about all defects or events that are detected by the other parts of the on-board monitoring system. Weighting factors are calculated for the different events, depending from their duration and severity. Additionally, for most incident types characteristic engine parameters are recorded for a short period of time before and after the failure or event have been detected in order to support the failure investigation on-ground.

All Incidents are displayed on the MDP after the flight.

The EHM reports all detected incidents to the Logistics sub-system of the EHM in order to initiate the necessary maintenance actions. Facilities will be provided by the EHM to support the investigation of incidents by showing information about similar events and performing statistical analyses.

4   Future Trends in EHM Systems

The development of future EHM systems will face a number of challenges that are mainly driven by the following two contrary trends:

- Stagnating or decreasing military budgets in most countries.
  Resulting from this a substantial reduction of the development costs as well as of the operational costs of aircraft weapon systems is necessary. The development of these systems must become more effective than today, the development times must be significantly reduced and the multiple development of similar functionality, e.g. for engine monitoring at testbed and at customer sites must be avoided.
  The maintenance costs for future military jet engines must be reduced via a better support and guidance of the maintenance personnel for all maintenance tasks and via an enhanced automation of monitoring and diagnosis functions in order to reduce the workload to the ground crews.
- Ever increasing customer requirements to the aircraft and engine systems related to utilisation capabilities, flexibility of usage, extension of system life, reduction of turn-around times, simplification of maintenance and other criteria.

Future EHM systems will have to cope with those requirements. Additionally, the increased requirements to the aircraft systems will lead to the introduction of new technologies into and to a higher technical complexity of the jet engines, their accessories and of the engine control and monitoring systems. This causes also increasing demands to the EHM systems.

4.1   Improvement Potentials for Future EHM Systems

The effects of the aforementioned trends on future engine monitoring and diagnosis systems including the engine health monitoring and logistic support systems have been analysed in MTU during a technology study. The goal of this study was the definition of an optimum concept for future control, monitoring and engine ground support systems which allows the fulfilment of the aforementioned increasing requirements and a considerable reduction of costs. The results of this study with respect to EHM systems will be summarised in the following sections. Although a complete differentiation between on-board and ground-based systems is not possible, this paper concentrates on the EHM related improvement potentials.

In addition to the analysis of future requirements, experiences from existing engine programs, namely the RB199 of the Tornado aircraft and the GSS/EHM for the EJ200 engine of the EuroFighter have been analysed to identify areas of problems and possible improvements of future systems.

Resulting from the analysis of increased requirements, technological trends and experiences from existing and productive engine systems, the following areas for potential improvements of the EHM systems in the future have been identified:

- Extension and optimisation of the monitoring and diagnosis functionality
- System architecture
- Development of monitoring and diagnosis systems

4.2   Extension and Optimisation of the Monitoring and Diagnosis Functionality

To cope with the aforementioned increasing demands to aircraft weapon systems and their jet engines at lower costs, a considerable number of technological improvements are expected to be introduced into future engine systems and thus will influence the development of future EHM systems.
Examples are

- Vectorisation of thrust with vector nozzles, requiring the implementation of thrust vector control and related monitoring tasks into the engine control system
- Optimisation of the engine control algorithms. Examples are performance seeking control, surge control or active oil systems. Resulting from this, increased monitoring and

diagnosis requirements are to be fulfilled to ensure the safety and reliability of those functions

- Closer integration of engine control and monitoring, supported by the integration of multiple on-board systems into one device. An example is the planned integration of todays DECU and EMU devices of the EJ200 engine into one device, with the option to integrate also the ODMS in the future.

The following list gives an overview about possible improvements of the monitoring and diagnosis functionality that should be considered for future systems:

- Introduction of expert systems for diagnosis. With these systems the specific knowledge of engine experts from industry or customer can be made available to all maintenance personnel at very low cost. Experiences made during engine development and during solution of problems in the past are automatically used for the solution of actual problems, reducing time and cost of maintenance and increasing the trustworthiness and understandability of diagnoses.
  It should be noted, that expert systems, due to their non-deterministic nature, are not suited for on-board monitoring tasks.
- Usage of modern analysis methods such as Bayesian (probabilistic) Networks to identify failures sources and neural networks to recognise characteristical patterns within aircraft signals (e.g. recorded vibration signatures)
- Thrust Monitoring (in conjunction with performance seeking control)
- Surge detection and control
- Detection of FOD and bird strike via inlet sensors or engine distress monitoring
- Detection of cable defects
- Active oil systems
- Re-calculation of life accounts after changes of lifing algorithms or of their parameters
- Earlier detection of defects via improved trend analyses

Many of these functions are built on very complex algorithms and large amounts of data and must be widely configurable. Therefore most of these algorithms can be executed on ground only. This requires the storage and transmission of large amounts of data by the on-board systems. Future systems will therefore have to support the continuous storage of relevant parameters during the whole flight and the transmission of these data to the GSS/EHM, where they will be stored for the whole life of an engine.

4.3   System Architecture (Integrated Monitoring and Ground Support System)

The flexibility and commonality of the actual EHM system is limited due to the following problems:

- The EHM is inseparably integrated into the health monitoring system of the aircraft. Parts of the engine related functionality and all basic functions and interfaces to the outside world are implemented by other ESS sub-systems.
  Thus a further development of the EHM strongly depends from modifications of other ESS sub-systems, resulting to high modification costs. Porting of on-board and off-board parts of the engine monitoring and diagnosis system due to the usage of the same engine in other aircraft systems requires a redevelopment of the EHM system.
  Another problem resulting from the distribution of the engine related functionality over a number of ESS sub-systems is, that the ensuring of the fulfilment of all requirements related to engine monitoring, diagnosis and maintenance is very complicated. There is a considerable risk, that functionality will be missed or duplicated in the completed ESS system, because the responsibilities for these functions are unclear.
- The complexity of the on-board system is too high.
  In the EuroFighter five on-board devices contribute to the collection and transfer of engine related data, which are distributed over 3 transfer devices. This causes high technical effort, high expenses and complicated co-ordination. Modifications and extensions of the on-board system affect a lot of devices. This and the technical complexity of the system make modifications complicated, expensive and risky due to possible side-effects.

- Engine data are transferred using the same transfer devices as aircraft data.
  The capacity of those systems is limited, all on-board systems compete for the storage space.
  The number of devices involved in engine data transfer is too high. Thus adaptations of transferred engine data to future requirements are nearly impossible, again expensive and time consuming.

All off these hindrances prevent the development of a really flexible, fully integrated engine monitoring, diagnosis and ground support system, that is easily adaptable to the ever-changing technological needs and customer requirements. The fulfilment of the requirements is significantly complicated, expensive and time consuming with the current system architecture and concepts.

Therefore the following improvements should be considered for future systems:
- Thorough integration of all engine related monitoring and diagnosis tasks into the EHM
- Standardised interfaces to the logistic system
- Usage of a dedicated engine data transfer medium

4.3.1   Thorough Integration of all Engine Monitoring and Diagnosis Tasks into the EHM

An essential condition to ensure the flexibility of future EHM systems and their adaptability to different requirements and aircrafts is the integration of all engine related monitoring and diagnosis tasks into the EHM.

There is a number of engine related functions in the ESS for the EuroFighter, that are not in the responsibility of the EHM:

- The Maintenance messages that are created on-board by the AETS function of the EMU are initially handled by the Aircraft System Health (ASH) sub-system of the ESS. The corresponding maintenance activities are initiated by the ASH system before the messages are passed to the EHM for further handling and analysis.
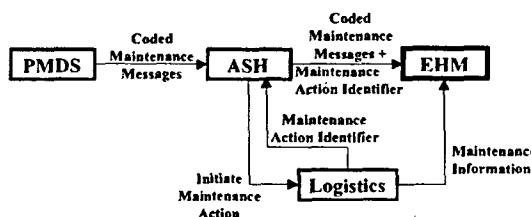

Figure 3: Transfer of Information related to AETS Maintenance Messages in the ESS

- The handling of the life accounts of engine parts is split between the EHM and the logistics sub-system. The EHM handles the life accounts of the critical parts that are supervised by the EMU, the accounts for all other life limited parts are handled by the logistics sub-system.
- Experience capturing functionality will be provided by the Experience Capturing system of the ESS. Although this functionality requires an in depth knowledge about the engine system, it is planned to implement this into another sub-system.

The aforementioned examples of a problematic distribution of engine related functionalities over different sub-systems result to the following weaknesses during development and advancement of EHM systems:
- The system design becomes unnecessarily complex.
- A number of additional interfaces have to be introduced between sub-systems.
- The development of the whole ESS is considerably complicated due to the high co-ordination effort that is needed to ensure, that all related functionality is provided and that no functionality is implemented twice.

- The development of distributed functionalities cannot be started before the last involved party starts with the development, resulting in a high program risk to the other parties.
- A porting of EHM systems with this distribution of functionality means in fact a complete re-development.

4.3.2   Standardised Interfaces to the Logistic System

From customers point of view only an integrated monitoring, diagnosis and logistic support system for the whole aircraft weapon system is thinkable, a differentiation between different systems for aircraft related tasks and engine related tasks is not acceptable.
There must be a common, uniform and consistent user interface. Therefore the integration of maintenance management tasks into the EHM is not possible since it would lead to two different user interfaces for aircraft and engine maintenance. Instead of this the EHM must be seamlessly integrated into the aircraft maintenance system. All engine defects must be reported to the central maintenance management system for the whole aircraft system, all EHM functionalities must be callable from the logistics sub-system.

This can be ensured in an effective and flexible way only, if there is a standardised interface to the logistics system. The specification of this interface must include features that allow the EHM to
- initiate maintenance activities after engine defects have been detected
- handle call-backs from the logistics sub-system to support the fault investigation and to provide engine specific maintenance guidance
- to get back information about completed maintenance activities
- get information about the aircraft configuration.

The development of such an interface, that allows flexible adaptations to special needs of a concrete system is supported by todays software component architectures.

4.3.3   Usage of a dedicated engine data transfer medium

A dedicated engine data transfer module (Portable Engine Data Store – PEDS) should be used for engine data instead of sharing the same transfer media for engine and aircraft data

A number of problems resulting from this shared usage of the data transfer devices for engine and aircraft data could be solved by the usage of such a device:
- The on-board system would become significantly less complex due the avoidance of additional interfaces for engine data transfer and of engine data processing capabilities that must be implemented otherwise into a number of devices just to handle the transfer of engine related data.
- Within the ESS, the engine data could be read directly by the EHM instead of their reading and decoding by another ESS system, splitting them from the aircraft data and transmission to the EHM, where they can be handled.
- The development of the engine transfer medium in the responsibility of the engine manufacturer would ensure, that the needs of the engine system related to data transfer are fully met.
- The development of engine data transfer mechanisms could be undertaken independently from the development of the mechanisms for aircraft data transfer.
- Changes in the transferred data would be significantly less complicated due to the smaller number of involved systems and manufacturers.
- A porting of the engine monitoring, diagnosis and ground support system would be significantly easier, because the same PEDS module could be used for different aircraft types. Additionally, a PEDS would allow the design of a complete fully integrated system of on-board devices, transfer media and ground support components

To avoid the implementation of an additional data transfer device into the aircraft, the PEDS should not be realised as a separate device. Instead of this, it should be a memory module that can easily be integrated into the aircraft data transfer devices.

The storage capacity of the PEDS should be large enough to allow the continuous recording of engine parameters with a resolution that is sufficient for ground based monitoring and diagnosis functionalities. In this case the BSD would no longer be needed for engine data recording, another device and a set of interfaces would become obsolete. Additionally, a complete data recording and archiving over the whole life of the engine would be possible. This is not the case today, because the BSD must be shared between aircraft and engine data.

4.3.4   Comparison of Actual and Optimised Architecture

The following figure shows the optimised architecture of the engine monitoring, diagnosis and ground support system, to be compared with the actual architecture as shown on Figure 1.
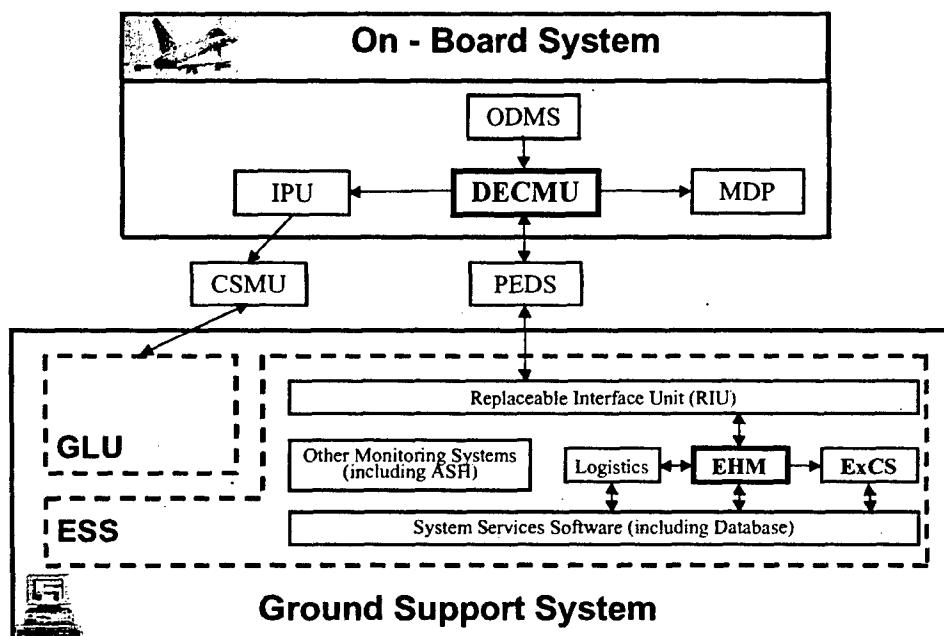

Figure 4: Optimised Architecture of the Engine Monitoring and Ground Support Systems of the EuroFighter

The optimised architecture includes all improvements that have been proposed and the introduction of an integrated control and monitoring on-board device (DECMU).

The optimum architecture represents an engine monitoring, diagnosis and ground support system with the following benefits in comparison to the actual system:

- Optimum integration between the on-board system, the engine data transfer media and the ground support system
- The distribution of functionality within such a system is very flexible.
- The system is considerably less complex. The number of devices and interfaces is substantially reduced.
- The system can be fully developed in the responsibility of the engine manufacturer, with less dependencies from the aircraft manufacturer.
- The development can be done at lower cost and shorter times.
- The fulfilment of engine related requirements can be ensured.
- Changes can be implemented faster and easier.
- The system is easily portable to other aircraft types.

4.4   Development of Monitoring and Diagnosis Systems

Beside the extension of the monitoring and diagnosis functionality and a better structured system architecture, potential for improvements of future EHM systems and for cost and development time reductions also lies in the development process of the system.

A better integration with development support systems and with other logistic support systems for other maintenance tasks beside the flight line maintenance should be aspired to provide a better reuse potential for developed system parts.
A number of systems with similar tasks as the EHM is needed for development, production and repair of the engine:

- Monitoring and set-up units to support the development of the control and monitoring system hard- and software
- Systems for monitoring, diagnosis and engineering data transfer and analysis at the engine testbed during development, certification and production pass-off tests
- Data transfer and analysis systems to be used at higher maintenance levels, e.g. engine repair&overhaul at customer and industry sites.

Currently, separate systems with similar functionalities are developed for the different stages of the product lifecycle.

An earlier design and development of the EHM, parallel with the on-board and data transfer parts of the engine monitoring and diagnosis system would significantly reduce the development risk.
Todays EHM systems are usually developed after the design of the on-board monitoring, control and diagnosis system and of the data transfer devices has been finalised.
So the EHM system has to deal with and to make the best use of the realities of the given systems, an optimisation of the on-board and transfer components to the needs of the ground based system is either not possible or requires a huge effort to modify these systems.
This causes additional effort in EHM system development as well as limitations to the functionalities of the ground based system.

To solve both problems, the development of future EHM systems should be done in parallel to the development of the on-board and of the data transfer systems. Parts developed for the EHM should be used already during development to support similar tasks. This would avoid the multiple development of similar systems for the different stages of the development cycle and for the operational phase of the system.

Additionally, really integrated and coherent engine monitoring, diagnosis and ground support systems could be developed. The usage of identical systems would improve the compatibility between customer and industry systems, i.e. between the EHM and the industry systems for repair&overhaul.

Integration and coherence could be fully validated during the different development phases, the EHM would be validated together with the other parts of the system. This would significantly improve the maturity of the whole system before the operational phase.

5   Summary and Conclusions

The EJ200 EHM will be a modern, state-of-the-art engine health monitoring system with a comprehensive and sophisticated monitoring and diagnosis functionality that provides extensive engine maintenance support and guidance to the ground crew. The EHM system will be seamlessly integrated into the overall Ground Support System for the EuroFighter.

However, continuous improvements of EHM systems are required to ensure that future EHM systems will meet the challenges resulting from the ever-increasing complexity of the engine system and due to continuously rising customer requirements that are to be fulfilled at lower cost.

Improvement potential has been identified in the following areas:
- Extension and optimisation of the monitoring and diagnosis functionality
- EHM System architecture
    - Thorough integration of all engine related monitoring and diagnosis tasks into the EHM
    - Standardised interfaces to the logistic system
    - Usage of a dedicated engine data transfer medium
- Development of monitoring and diagnosis systems
    - A better integration with development support systems and with other logistic support systems outside the flight line maintenance
    - Earlier development of the EHM, parallel with the on-board and data transfer parts of the engine monitoring and diagnosis system.

These improvements result to a number of benefits:
- Improved monitoring and diagnosis of engine defects
- Reduced complexity of the engine monitoring, diagnosis and ground support system
- Improved portability and modifiability of EHM systems
- Reduced development time and cost.

Paper 11: Discussion

Question from L Jaw – Scientific Monitoring Inc, USA

Can you describe what you meant by an 'active oil system'?

Presenter's Reply

Preliminary thought on this is to utilise valves to control oil temperature and quantity, in order to match them to the requirements of specific engine operating conditions.